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J.W.E. Harris, R.I. Alfaro, A.F. Dawson and R.G. Brown

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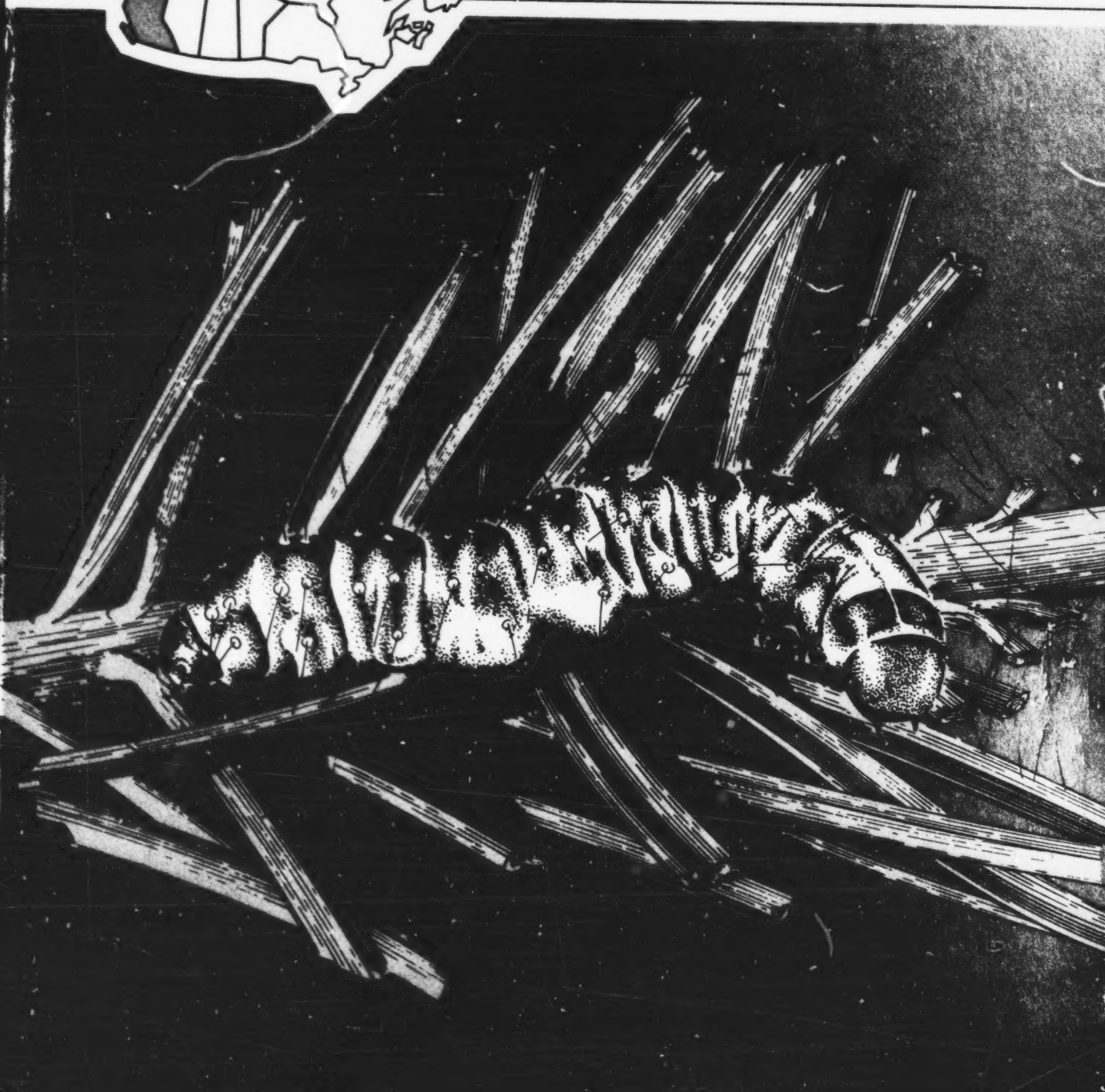

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Abstract

Populations of the western spruce budworm, *Choristoneura occidentalis*, an important forest defoliator of Douglas-fir stands in British Columbia, have periodically increased to infestation levels for 1 to 13 years at various localities before declining. Trees severely defoliated for several years suffer top-kill, deformity, and mortality. Infestations have occurred primarily in the Coastal and Interior Douglas-fir Biogeoclimatic zones, but have extended into the Coastal Western Hemlock Zone and Interior Cedar-Hemlock Zone.

Since 1909, six infestations of the western spruce budworm have occurred in B.C. The last three infestations have been the most extensive, and the area of defoliation has increased in each case. In the latest infestation, which continues in 1984, there were 226 000 ha of Douglas-fir stands defoliated in the peak year of 1976.

Before an outbreak, the first warning is an increase in the number of samples containing budworm larvae (percent positive samples) to 20% or higher. If in a subsequent year the average number of larvae per sample increases and localized defoliated areas are observed, an increase in the intensity and area of defoliation is likely the next year. If in following years, the percent positive samples and average number of larvae per sample increase markedly, widespread defoliation can be expected.

Résumé

La tordeuse occidentale de l'épinette (*Choristoneura occidentalis*) est un fléau des douglasières de la Colombie-Britannique, et ses effectifs ont atteint des seuils épidémiques pendant 1 à 13 ans, dans diverses localités, avant de se résorber. Après une défoliation grave de plusieurs années, la cime dépérit, l'arbre se déforme puis il meurt. Les infestations sont surtout survenues dans les zones biogéoclimatiques du douglas de l'Intérieur et de la Côte, mais elles ont gagné celles de la pruche occidentale, sur la Côte, et celle du thuya et de la pruche, de l'Intérieur.

Depuis 1909, il y a eu six infestations de la tordeuse occidentale en Colombie-Britannique. Les trois dernières ont été les plus générales, et la superficie défoliée a augmenté chaque fois. La dernière infestation, qui dure encore en 1984, a été la plus dévastatrice en 1976, alors que 226 000 ha des douglasières ont été défoliés.

Le premier signe annonciateur d'une infestation à venir est que le taux d'échantillons contenant des larves de tordeuse (pourcentage d'échantillons positifs) dépasse 20%. Si, au cours d'une année ultérieure, le nombre moyen de larves par échantillon augmente et qu'on observe des zones localisées de défoliation, il est probable que, l'année suivante, l'intensité et la superficie de défoliation augmenteront. Si, dans les années ultérieures, le taux d'échantillons positifs et le nombre moyen de larves par échantillon augmentent considérablement, on peut s'attendre à une défoliation généralisée.

Introduction

The western spruce budworm, *Choristoneura occidentalis* Freeman (Lepidoptera: Tortricidae), feeds primarily on Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in British Columbia (B.C.). Although normally present in low numbers and unnoticed in the forest, budworm populations periodically increase to such levels that they visibly damage host foliage. These increases in population, caused by increased reproduction and survival or by spread from other infested locations (Shepherd 1977), are known as population outbreaks. The period of high populations and noticeable defoliation, which may persist for several years, is termed an infestation. An infestation is considered to last from the first to the final year in which host trees sustain visible defoliation. Defoliation has mostly occurred in the Interior Douglas-fir Biogeoclimatic Zone (U.B.C. Faculty of Forestry 1983), in the ecotone of this zone with the Coastal Western Hemlock Zone in the Pemberton and Hope areas and with the Interior Cedar-Hemlock Zone in the Adams Lake-Shuswap Lake area, and within the Coastal Douglas-fir Zone on southeastern Vancouver Island. The first recorded infestation in B.C. occurred on southeastern Vancouver Island from 1909 to 1910 (Mathers 1931). Since then, five other infestations have been recorded in B.C., and the largest infestation occurred near Pemberton, Hope and Cache Creek.

Budworm larvae prefer the current year's foliage, but in severe infestations older foliage is also consumed. The upper crown of host trees is usually defoliated first. If severe defoliation continues for several years, losses in radial and height growth, and top-kill and tree mortality will occur (Shepherd *et al.* 1977; Collis and Van Sickle 1978; Alfaro *et al.* 1982; Thomson *et al.* 1982; Van Sickle *et al.* 1983). Stem deformities, which reduce the merchantable volume, often develop during the recovery from severe top-kill.

Defoliator populations, and the damage they cause, are monitored annually throughout B.C. by the Forest Insect and Disease Survey (FIDS) of the Canadian Forestry Service. Before 1949 there was no formal sampling plan for estimating populations, and defoliation boundaries may not always have been reliably recorded . Beginning in 1949, populations were measured annually by FIDS staff at a province-wide network of ground sampling points (Harris 1976). Observations of tree defoliation and mortality have continued to the present, and have increased in accuracy as more use was made of aircraft for detecting and appraising damage (Harris and Dawson 1979).

This report, patterned on a similar report on western hemlock looper, *Lambdina fiscellaria lugubrosa* (Hulst) (Harris *et al.* 1982), describes the history of western spruce budworm infestations in B.C., summarizing tree damage since 1909 and larval populations since 1949. In the latter case, for five geographic areas where infestations have occurred, the average number of larvae per sample and percent samples containing budworm larvae (percent positive samples) were calculated and plotted so that population changes could be readily seen. Budworm populations before and during the course of each infestation were then examined and thresholds identified which might serve as a warning of impending outbreaks.

Methods

Information on the western spruce budworm in British Columbia was obtained from various published and unpublished records dating back to 1909. Quantitative larval data for 1949-1983 were retrieved from the FIDS computer data file (Harris 1976). The most important literature source was the FIDS annual regional report which summarizes forest pest conditions in B.C.[1] Mathers (1931, 1932) outlined the earlier infestations up to 1930, and Silver (1960) described the infestation in the 1950s in the Pemberton-Hope area.

The abundance of western spruce budworm larvae on Douglas-fir was determined for each year from records collected by FIDS at 73 permanent sampling stations (Fig. 1) using the 3-tree

[1] By Forest Region since 1920, in "Annual District Report, Forest Insect and Disease Survey" and "Annual Forest Insect and Disease Conditions", Canadian Forestry Service, Victoria; and for the Province since 1937, in "Annual Report of the Forest Insect and Disease Survey", Canadian Forestry Service, Ottawa. These reports were compiled from insect collections and damage records taken each summer on the ground (Harris 1976) and from annual aerial defoliation surveys (Harris and Dawson 1979).

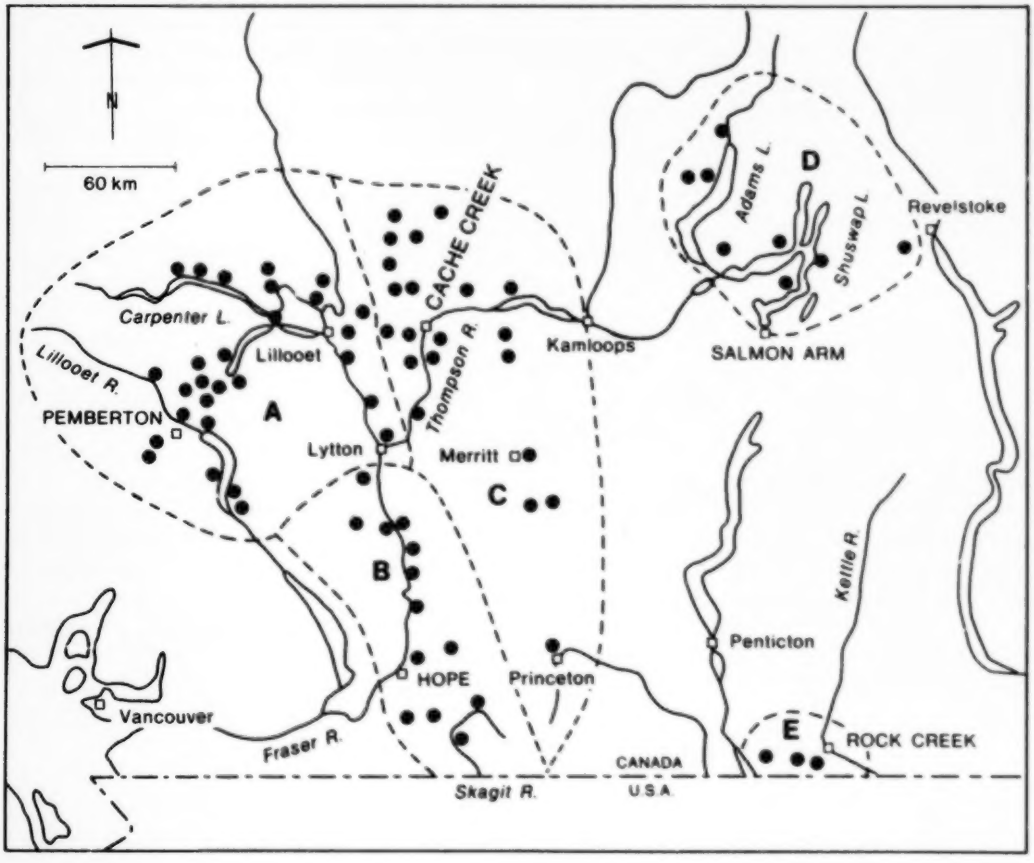

Fig. 1. Western spruce budworm Forest Insect and Disease Survey permanent sampling stations in British Columbia (●) from 1949-1983; samples were combined into the following major study areas to determine average numbers of larvae per sample and percent positive samples in each area: (A) Pemberton, (B) Hope, (C) Cache Creek, (D) Salmon Arm, (E) Rock Creek.

beating method described by Harris (1976). The average number of larvae per sample and the percent positive samples from Douglas-fir from 1949-1983 were calculated and graphed for five geographic study areas in southern Interior B.C. (Fig. 1, A-E). These areas were groups of drainages in which defoliation had occurred between 1949-1983 (Fig. 2), and were selected based on the temporal and geographic pattern of defoliation development that had occurred in the two infestations since 1949. Outside these areas, six localized spots where defoliation occurred for only one year (Fig. 2) were omitted from the larval population analysis as well as the southern Vancouver Island area (Fig. 2, location 19) where defoliation has not been recorded since 1930.

Results

Areas in which western spruce budworm defoliated Douglas-fir in B.C. have been variable in size. The cumulative total area defoliated over all years is about 340 000 ha (Fig. 2). Since 1909, there have been six infestations in B.C. (Table 1, Fig. 3 and 4). The first five lasted from 2 to 11 years before subsiding, but the current infestation, which started in 1967, has lasted 17 years and reached a peak in 1976 when 226 000 ha of Douglas-fir were defoliated. This infestation continues but on a reduced scale. The six infestations are described in greater detail in the following descriptions based on damage data from 1909-1983. Larval populations (calculated for each of the five major geographic study areas) were then summarized from 1949-1983, comparing budworm numbers at different stages of the last two infestations, to determine thresholds for predicting future outbreaks (Table 2).

1909-1910

In 1909, the first recorded damage by western spruce budworm feeding on Douglas-fir in British Columbia occurred on southeastern Vancouver Island at Victoria and Duncan (Mathers 1931). In 1910, the area most severely infested was from Maple Bay near Duncan south to the Saanich Peninsula and on Saltspring Island (Fig. 4a). Some mortality of second growth Douglas-fir occurred where there was repeated defoliation. However, 1909 was considered to be the peak year, and there was an apparent decrease in intensity in 1910.

1916-1919

A small infestation occurred in the Lillooet area from 1916-1919 (Mathers 1931) (Fig. 4a). Tothill (1923) reported that natural checks (larval parasites and birds) brought about a reduction of the infestation, which subsided entirely in 1920.

1923-1930

In 1923, the budworm was reported at Glade on the Kootenay River near Castlegar. Defoliation occurred on 1200 ha in the Bridesville-Rock Creek area in the Kettle River Valley (Fig. 4b) which persisted until 1928 (Mathers 1931).

In 1926-1927, light to severe defoliation of immature Douglas-fir and grand fir (*Abies grandis* (Dougl.) Lindl.) occurred at five locations on southeastern Vancouver Island: Craig near Parksville, Wellington north of Nanaimo, Yellow Point near Ladysmith, Maple Bay near Duncan, and Colwood near Victoria (Fig. 4b). The budworm was also reported on Gabriola Island near Nanaimo. In 1928, the infestation subsided north of Nanaimo, but expanded in the Yellow Point, Maple Bay, and Colwood areas. In 1929, the original area of defoliation at Yellow Point subsided, but a new area of defoliation occurred nearby. At Maple Bay, defoliation decreased in intensity in 1929, but the area of defoliation expanded in the Colwood area, from Finlayson Arm east to Thetis Lake south to Glen Lake and Albert Head. In 1930, the infestation subsided at Yellow Point and Maple Bay and declined at Colwood, collapsing completely in 1931. During the infestation, tree mortality was limited to a few suppressed trees, however, most defoliated trees recovered by putting out secondary growth, even when defoliation was as severe as 75%.

Mathers (1931) reported that in 1930 the budworm was again active in the Lillooet area, but no details were recorded.

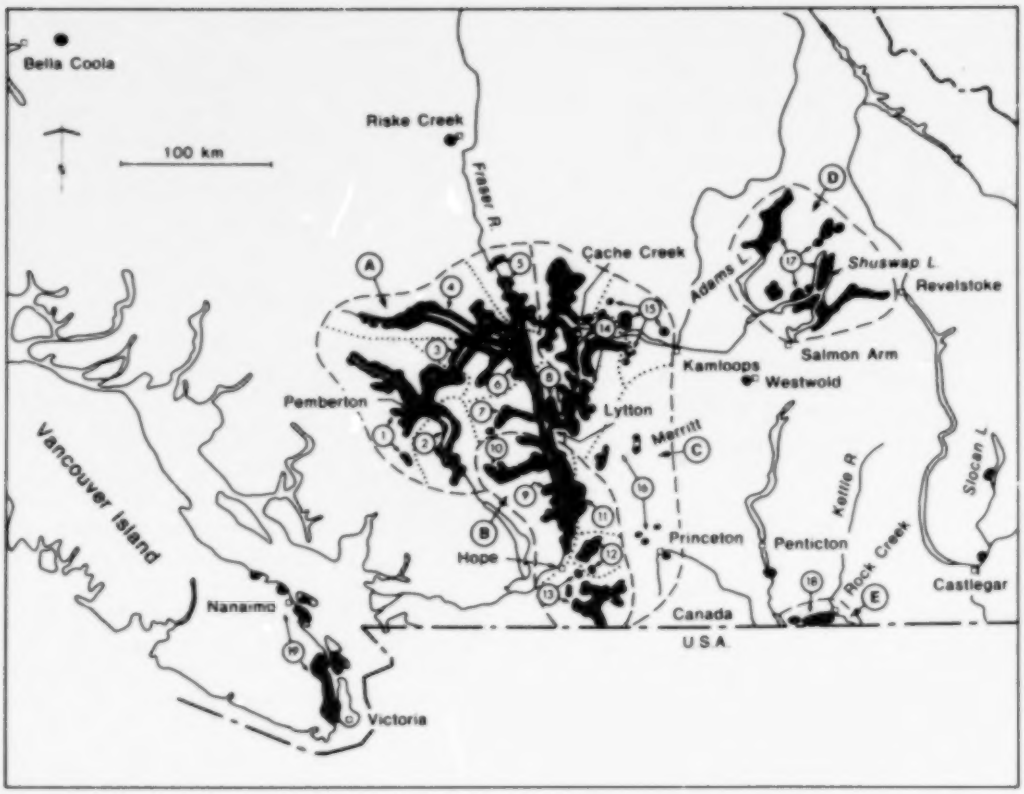

Fig. 2. Maximum extent of western spruce budworm in British Columbia from 1909-1983. A-E identify study areas (See Fig. 1) from which permanent sampling station records were extracted and averaged from 1949-1983. The following locations are distinct drainages or areas where defoliation has occurred in more than one year:

(1) Lillooet River drainage north of Lillooet Lake, including Birkenhead River drainage, Rutherford Creek, Soo River, Green River; Gates River, Haylmore and Blackwater creeks; Cheakamus Lake. (2) Lillooet Lake, including lower Lillooet River south to Gowan Creek. (3) Seton Lake, Anderson Lake, Whitecap Creek, Cayoosh Creek, Mission Pass. (4) Carpenter Lake, Downton Lake, upper and lower Bridge River, Yalakom River. (5) Pavilion area, north along the Fraser River to Big Bar Creek, Pavilion Mountain, Pavilion, Crown, and Kelly lakes. (6) Lillooet area, south along the Fraser River to Texas Creek, Fountain Creek. (7) Lytton area, Fraser River south of Texas Creek to north of Kwoiek Creek, Stein River. (8) Botanie Creek. (9) Fraser Canyon area of Fraser River from Hope to Kanaka, Kwoiek Creek, Nahatlatch Lake. (10) Upper Nahatlatch River drainage. (11) Anderson River drainage. (12) Coquihalla River drainage, Sowaqua Creek. (13) Skagit River drainage, Sumallo River, Snass Creek, Skaist River; Nicolum and Silverhope creeks. (14) Thompson River from east of Lytton to Savona; Bonaparte River drainage from Cache Creek to north of Clinton, Hat Creek, Loon Lake. (15) Kamloops Lake area; Pass Valley, Sabiston and Carabine creeks, Tranquille River, Tunkwa Lake. (16) Merritt-Princeton area; Spius and Prospect creeks. (17) Adams Lake and upper Adams River, East Barriere Lake; Shuswap Lake drainage, including Scotch Creek, Seymour River, Ratchford Creek, White Lake, Eagle River from Sicamous to Clanwilliam Lake near Revelstoke. (18) Rock Creek to Bridesville; Anarchist Mountain near Osoyoos. (19) Southeastern Vancouver Island.

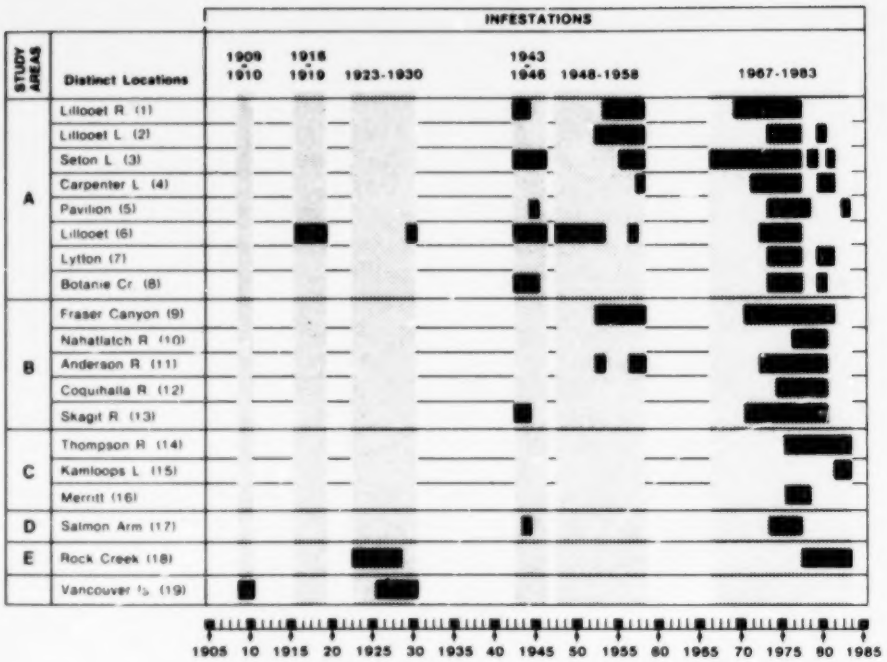

Fig. 3. Infestations of western spruce budworm in British Columbia, 1909-1983, with distinct drainages or locations (1-19) (Fig. 2) where defoliation has occurred in more than one year.

1943-1946

In 1943-1944, severe defoliation of Douglas-fir occurred from Pemberton to Anderson Lake, along the Lillooet River north from Pemberton, near Lillooet at Mission Ridge, Mt. McLean and Fountain Creek, along the Bridge River, in the Botanie Valley near Lytton, and at Skaist River near Hope, where alpine fir (*Abies lasiocarpa* (Hook.) Nutt.) and Engelmann spruce (*Picea engelmannii* Parry) were also attacked (Fig. 4b). In 1944, young Douglas-fir were defoliated at the mouth of upper Adams River. In 1945, the infestation collapsed at Pemberton and Skaist River, and decreased in intensity at Mt. McLean, Mission Ridge and Botanie Valley. However, near Lillooet at Cayoosh and Fountain creeks defoliation increased in intensity and was severe at Bridge River. In 1946, the infestation continued to decrease at Mission Ridge and Mt. McLean. Defoliation was light near Pavilion at Fountain Creek and Crown Lake and severe in spots at Yalakom River. Noticeable defoliation occurred on Pavilion Mountain and at Kelly Lake, southwest of Clinton, where larvae were heavily parasitized. In 1947, high numbers of larvae were present in some of the above locations, but there was no record of defoliation.

1948-1958

In 1948-1952, light defoliation[2] occurred near Lillooet in the Fountain Creek Valley, extending from 460 to 1070 m in elevation, but this de-

[2] The criteria used by FIDS to classify defoliation from the air were as follows:— **light**: discolored foliage barely visible from the air, some branch tip and upper crown defoliation; **moderate**: pronounced discoloration, noticeably thin foliage, top third of many trees severely defoliated, some completely stripped; **severe**: bare branch tips and completely defoliated tops, most trees more than 50% defoliated.

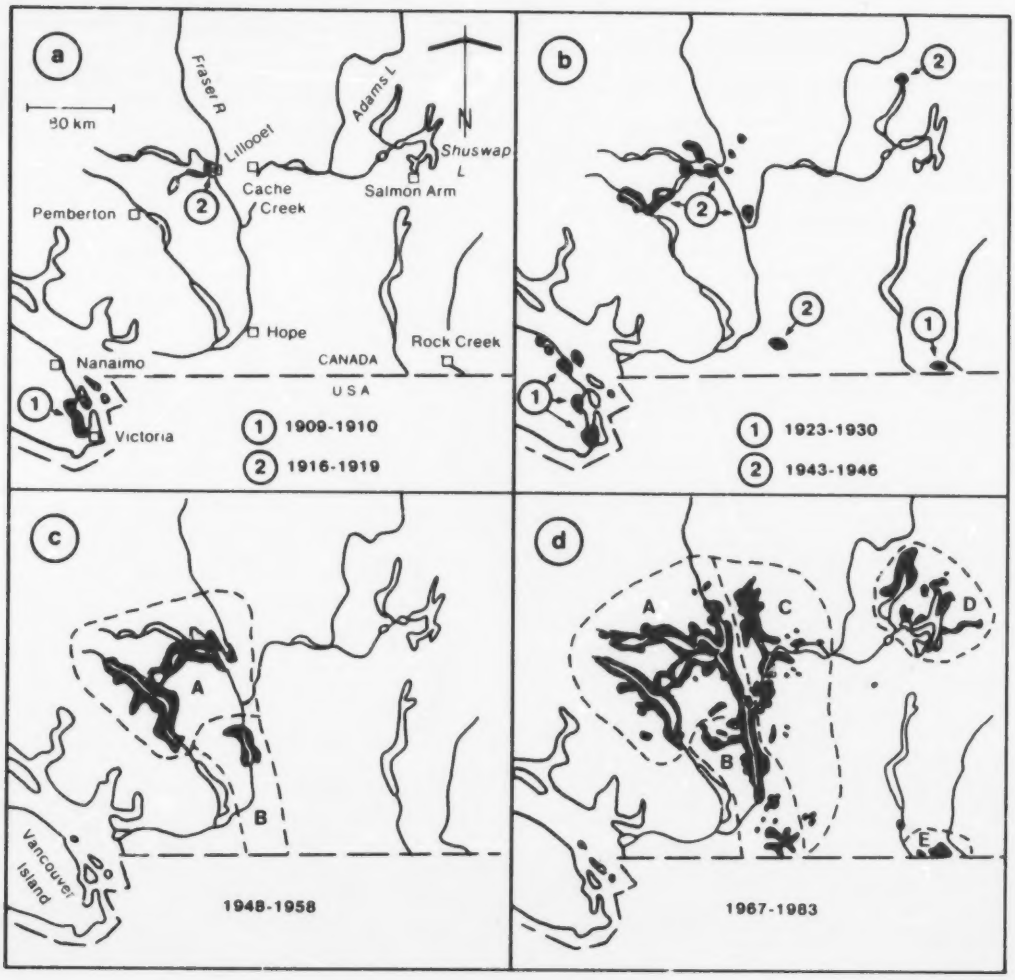

Fig. 4. Infestations of western spruce budworm in British Columbia, 1909-1983. Study areas A-E as in Fig. 1 (also in b. near Lillooet in 1930; exact location unknown).

creased in 1953 (Fig. 4c). In 1952-1953, populations increased considerably near Hope in the Fraser Canyon and along the Nahatlatch and Anderson rivers, and near Pemberton in the Lillooet River Valley. In 1953, light defoliation was evident for several kilometres along the Fraser Canyon and Nahatlatch River, and severe defoliation of current year's foliage occured on 100 ha at Anderson River, but no aerial survey was conducted. Light defoliation occurred along the Lillooet River between Harrison and Lillooet lakes. In 1954, the infestation expanded along Lillooet Lake and River from Gowan Creek to Pemberton and in the Fraser Canyon from Scuzzy Creek to Nahatlatch Lake, with two small areas of defoliation at Haylmore Creek northeast of Pemberton. In 1955, the infestation again expanded along the Lillooet River north to Pebble Creek and in the Fraser Canyon south to Spuzzum, and new defoliation was recorded from Pemberton to Birkenhead Lake and D'Arcy. Moderate to severe defoliation occurred, with limited tip and shoot killing, extending from valley floors up to 920 m. In 1956, the infestation expanded further with new areas from Blackwater Creek east along Anderson and Seton lakes to Lillooet, and southwest of Pemberton to Tisdall. Light to severe defoliation was recorded with

some scattered top-kill in the older infested areas.

In 1957, there was little change in the intensity or area defoliated (the Fraser Canyon area was not mapped from the air in 1957). Light defoliation was recorded from Lillooet to Texas Creek, along the west side of the Fraser River. In 1958, the infestation spread from Pemberton to Alta Lake with new areas of defoliation at Bridge River northwest of Lillooet and at Anderson River near Boston Bar. In 1959, the infestation collapsed after causing severe defoliation in some areas since 1954. Only traces of defoliation were observed and trees previously stripped of upper foliage produced new growth.

1967-1983

Western spruce budworm defoliation in this period occurred in the Pemberton, Hope, Cache Creek, Salmon Arm, and Rock Creek areas and, in isolated patches, at Slocan Lake, Okanagan Falls, Westwold, Riske Creek, and Bella Coola. Fig. 4d outlines the main area of defoliation in this infestation.

Pemberton, Hope and Cache Creek areas. Detailed maps showing the progression of defoliation from 1970 to 1983 for these three study areas combined are given in the Appendix. In 1967-1968, moderate to severe defoliation occurred on a small area at 1070-1190 m elevation at Mission Mountain near Lillooet, which covered 160 ha in 1969. In 1968-1969, populations increased to the south and west in the Pemberton and Hope areas. In 1970, light to severe defoliation of Douglas-fir occurred on over 6700 ha in the Pemberton area along Soo River, Rutherford Creek, from Pemberton to Salal Creek, and at Haylmore Creek, Mission Mountain, Whitecap Creek and Seton Lake. At Salal Creek, amabilis fir (*Abies amabilis* (Dougl.) Forbes) were also attacked in 1970 and again in 1971 along with alpine fir. The infestation expanded in 1971 to over 15 500 ha; new areas of defoliation occurred near Pemberton at McGillivray Creek, Blackwater Creek-Birkenhead Lake, and near Hope in the Fraser Canyon and at Tashme on the Hope-Princeton Highway. In 1972 there was a further general expansion so that over 40 400 ha were defoliated; the infestation spread in the Pemberton area to Carpenter, Gun, Downton and Cheakamus lakes, and Kwoiek and Cayoosh creeks. Light to moderate defoliation occurred in most areas, with some top-kill and mortality of understory trees. In 1973, there was a further expansion to over 72 600 ha. New areas of defoliation occurred near Hope at Eight-mile Creek, Sumallo River, Anderson River, and Nahatlatch Lake, and at Bridge River north of Lillooet and Mount Currie near Pemberton. Repeated defoliation over several years resulted in scattered top-kill and tree mortality.

In 1974, the infestation increased to 96 000 ha, with new areas of defoliation occurring south of Pemberton at Lillooet Lake, near Hope at Skagit River, Silverhope Creek, and Skaist River, along the Fraser River at Pavilion, Fountain Valley, Lillooet, and Lytton, and near Lytton at Botanie Creek. In the Pemberton area the infestation decreased in intensity. In 1975, the infestation continued to decline along Lillooet River north of Pemberton, but expanded at Lillooet Lake, Fraser Canyon, Nahatlatch Lake, Sumallo River, Skagit River, Downton Lake and Botanie Creek, with new areas from Lytton to Lillooet along the Fraser River and along the Coquihalla River near Hope, where light defoliation occurred. Small patches of light defoliation occurred at Kelly Lake near Clinton. The total area infested was over 116 000 ha.

In 1976, the infestation expanded and intensified near Hope in the Fraser Canyon and along the Coquihalla, Skagit, and Sumallo rivers and continued to decline in the Lillooet River Valley northwest of Pemberton. Tree mortality and top-kill were evident at Rutherford and Railroad creeks near Pemberton and at Trafalgar and Tsileuh creeks in the Fraser Canyon. The infestation also intensified in the Carpenter Lake-Bridge River Valley and in the Lytton-Lillooet area. New areas of defoliation occurred along the Fraser River north of Pavilion, at Oregon Jack Creek near Cache Creek, between Lytton and Spences Bridge on the Thompson River, and along the Stein River west of Lytton. Traces of defoliation were recorded near Merritt and Princeton. Light defoliation occurred again south of Clinton at Kelly Lake. Total area affected was 189 000 ha. In 1977, the infestation expanded to 199 000 ha. There was a general increase of moderate and severe defoliation near Hope along the Fraser Canyon, Skagit River, Sumallo River, and Coquihalla River, and in the Pemberton area at Lillooet River, Birkenhead River, Bridge

River, Carpenter Lake, and Yalakom River. New areas of defoliation were noted in the upper Nahatlatch River Valley, in the Cache Creek-Merritt-Princeton area, south of Clinton, and on both sides of the Fraser River at Big Bar Creek.

In 1978, the infestation declined to 31 500 ha of mostly light defoliation. No defoliation was recorded along the Lillooet or Bridge River valleys, the lower Thompson River, and between Lytton and Lillooet along the Fraser River. Patches of defoliation occurred in the Fraser Canyon and along the Skagit and Coquihalla rivers. Defoliation declined in the area south of Clinton. Mainly light defoliation occurred on over 5200 ha near Cache Creek and north of Lillooet. Moderate defoliation occurred on 110 ha south of Walhachin east of Cache Creek. A trace of defoliation was encountered near Merritt at Spius Creek and at August Lake near Princeton. In 1979, a further decline in the infestation occurred near Hope in the Fraser Canyon-Skagit River area, and patches of light to severe defoliation were recorded on 16 420 ha. In areas previously defoliated, noticeable top-kill and tree mortality (appearing as grey stands) occurred on 5700 ha in the Pemberton and Hope areas. Defoliation increased along the Coquihalla River where there were 3290 ha of mainly severe defoliation, and in the Clinton-Cache Creek-Lytton area where 27 000 ha of mainly light defoliation occurred. Two areas of very light defoliation occurred at Anderson Lake and Mission Mountain.

In 1980, there was an increase in the area of recorded defoliation in the Fraser Canyon-Skagit River area (mainly moderate-severe) and from Lytton to Clinton (mainly light) to over 80 900 ha from 46 800 ha in 1979. Defoliation was again recorded along Carpenter Lake and the Stein River where it had not occurred since 1977. At lower Lillooet River two small patches of moderate defoliation were recorded. In the Pemberton and Hope areas, within stands previously defoliated, up to 39% of the Douglas-fir had top-kill and 28% were dead from repeated defoliation or in combination with bark beetle attack. Tree mortality and top-kill were evident at Cornwall Creek near Cache Creek, and Marshall Creek near Carpenter Lake where repeated severe defoliation had occurred. At Hart Ridge near Clinton, about 5% of understory and intermediate trees were killed after four years of defoliation. In 1981, defoliation in the Hope area was reduced to 380 ha of severe defoliation at Urquhart Creek. At Haylmore Creek near Pemberton there were 40 ha of very light defoliation and near Carpenter Lake there were 65 ha of light defoliation at Marshall Creek. In the Spences Bridge-Cache Creek-Clinton area, defoliation was also reduced from 1980; over 21 000 ha of mainly moderate defoliation were recorded.

In 1982, no defoliation was observed in the Pemberton-Hope-Lillooet area and few larvae were collected in beating samples. Defoliation again decreased in the Spences Bridge-Cache Creek-Clinton area to 16 000 ha of mainly light to moderate defoliation, and new areas of defoliation were noted at Sabiston and Carabine Creeks. In 1983, the defoliated area increased considerably in the Spences Bridge-Cache Creek-Clinton-Savona area to 73 550 ha of mainly light defoliation, and new defoliation occurred at Tranquille River and Tunkwa and Pavilion lakes. A major expansion occurred in the Clinton area, resulting in a six-fold increase in recorded defoliation, but some of this was from very light feeding. High larval and egg mass counts indicate continued defoliation in 1984, especially near Cache Creek and Clinton.

Salmon Arm Area. Light to moderate defoliation occurred along the upper Adams River on 640 ha in 1974. This expanded to 3800 ha in 1975, and new defoliation was reported along Adams Lake, near Momich Lake, Gollen Creek and Harbour lakes (Fig. 4d). The area of defoliation increased considerably in 1976 to 37 000 ha of moderate to severe defoliation, including new areas along Shuswap Lake, at Scotch Creek, Sicamous, Seymour River, Anstey Arm, and Mara Lake. In 1977, the infestation decreased to 10 520 ha of light defoliation and new areas of defoliation were recorded at White and East Barriere lakes and at Clanwilliam Lake near Revelstoke where 25 ha were moderately defoliated. In 1978, larval populations were still present, but no visible defoliation occurred, and in fall surveys no egg masses were found. Populations collapsed in 1979.

Rock Creek Area. In 1977, light defoliation occurred in the Kettle River Valley at Johnstone Creek near Rock Creek (Fig. 4d). In 1978, trace defoliation occurred on Anarchist Mountain near Osoyoos and light defoliation of Douglas-fir and

western larch (*Larix occidentalis* Nutt.) occurred at Johnstone Creek on 80 ha. This increased in 1979-1980 to moderate defoliation on 200 ha. In 1981, defoliation increased in intensity and expanded to 1000 ha from Rock Creek to Bridesville, but this decreased in intensity in 1982, though beating samples averaged higher larval counts. In 1983, there was a further decrease in defoliation, and about 300 ha of trace defoliation (noticeable only on the ground) were recorded along Johnstone Creek. Larval counts were high at Johnstone Creek in 1983, so defoliation may continue in 1984.

Other Areas. In 1970, light to moderate defoliation was recorded on current year's growth of Douglas-fir at Firvale near Bella Coola (Fig. 2). In 1975, light defoliation occurred in small patches of Douglas-fir near Riske Creek. In 1976, trace defoliation was recorded at Westwold near Falkland and Okanagan Falls near Penticton. In 1977, light defoliation occurred at Cove Creek on the west side of Slocan Lake.

Discussion

Infestation Periodicity

A historical knowledge of areas damaged by spruce budworm will aid in defining hazard zones and selecting locations for future sampling. High priority sampling areas would be those where consistently high larval populations and visible damage have occurred (Harris *et al.* 1981) and especially those where defoliation has been repeated in two or more infestations (Figs. 3, 4 and 5). An increase in the number of larvae per sample and in the frequency at which larvae occur in samples should alert the observer to monitor these stands more closely. Where a possible problem is recognized, the economic values at risk should be assessed and control action should be prepared.

The periods of infestation in the areas studied are presented in Figure 3. On Vancouver Island, populations twice reached damaging levels, in 1909-1910 and in 1926-1930, but not since. In the Pemberton area, five periods of defoliation were recorded. Defoliation was localized near Lillooet in 1916-1919 and 1930 (exact locations unknown) and widespread during the other three periods. In the Hope area defoliation occurred in the last three infestation periods. Defoliation was localized at Skaist River in 1943-1944, but was more extensive in the last two periods. In the Cache Creek area defoliation occurred only in the last infestation. Localized defoliation occurred in 1944 in the Salmon Arm area and was extensive in the last infestation. In the Rock Creek area localized defoliation occurred in two infestations, in 1923-1928 and in the last infestation. Thus, with the exception of the two early records near Lillooet, where the exact locations were not indicated, defoliation has not occurred in any area for more than three infestation periods in this century (Fig. 5).

Annual radial growth from two affected trees sampled at Log Creek, near Hope, were also used to study the periodicity in budworm infestations in B. C. (Fig. 6). Only the earlier years, 1787 to 1899, are shown for the first tree because the extremely small annual radial increments of this 193-year-old tree in later years masked the effect of any possible defoliation on radial growth. Four budworm infestations, which occurred at intervals of 15 to 41 years, appear to have occurred in this area between 1787 and 1899. Radial growth of the second tree, which was 105 years old, shows three additional infestations which occurred at intervals of 20 to 37 years between 1899 and 1980. The two later infestations are documented. Similar infestation histories, based on radial increments, were reported for the Railroad Creek area, near Pemberton, B.C. (Shepherd *et al.* 1977 and Alfaro *et al.* 1982) and for the eastern spruce budworm (*Choristoneura fumiferana* (Clem.)) in eastern Canada (Blais 1983).

Population Records

More detailed estimates of budworm populations became available when tree beating sampling for defoliator larvae began in 1949. Since then, there have been two western spruce budworm infestations in the southern Interior, one between 1948 and 1958 and the other between 1967 and 1983.

Increases, peaks, and declines in the area of visible defoliation taken from aerial surveys and larval populations measured at permanent sampling stations either coincided or occurred within one to several years of each other (Fig. 7). In the Pemberton area, larval populations peaked in 1958 and 1975 and defoliation peaked in 1958 and

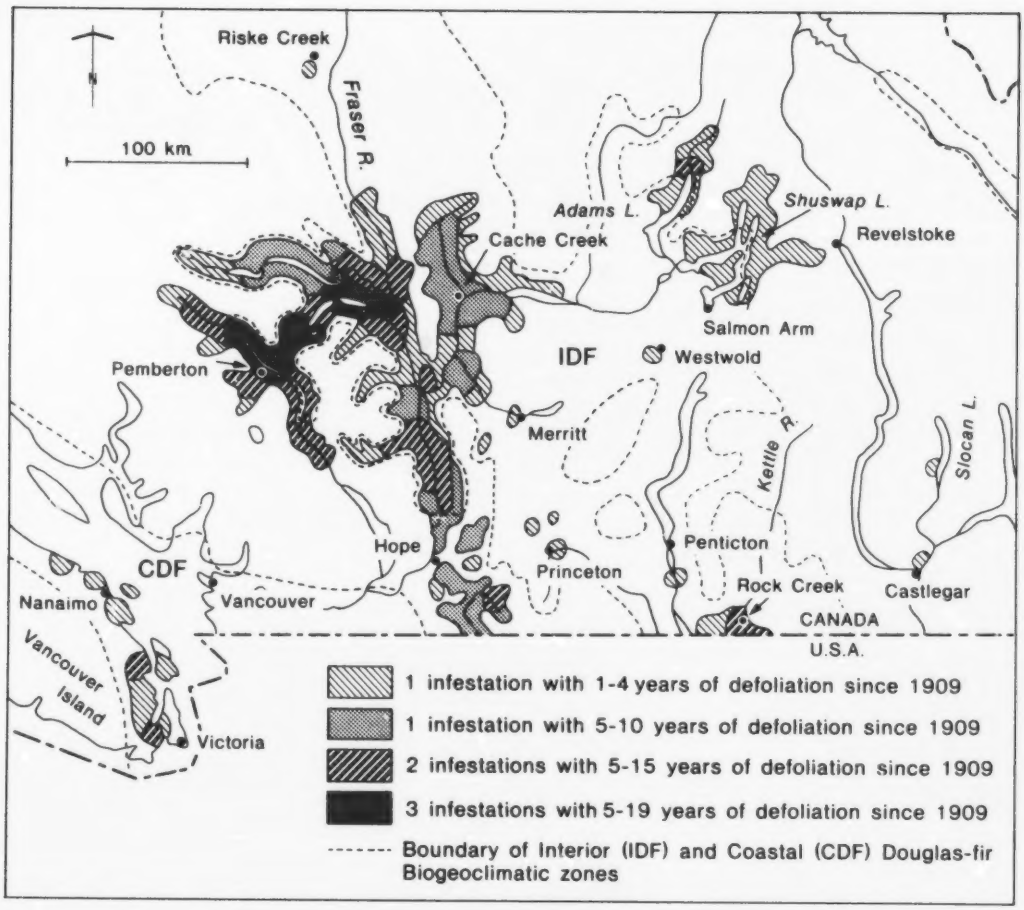

Fig. 5. Locations most likely to have western spruce budworm infestations in British Columbia, rated by the number of major infestations and years of defoliation that have occurred at each location since 1909.

1976. In the Hope area, larval populations peaked in 1954 and 1977 and defoliation peaked in 1956 and 1977. In the Cache Creek area, larval populations peaked in 1979 and defoliation peaked in 1980 but, after dropping, both rose sharply to even higher levels in 1983. In the Salmon Arm area, the peak in larval populations occurred in 1975, one year before the peak of defoliation in 1976. In the Rock Creek area, the peak in larval populations (1978) preceded that of visible defoliation by three years (1981).

Sharp increases in larval populations and the percentage of samples containing budworm larvae (percent positive samples) generally were accompanied by increases in the area of defoliation. Study of data from seven major population increases indicate population levels that might forecast impending defoliation or population peak or decline (Fig. 7). Two years before visible defoliation, the percentage of positive samples averaged 35% and the average number of larvae per sample was 2 (Table 2); in the year before the first visible defoliation, the percentage of positive samples rose to 48% and the average number of larvae per sample rose to 3. In the year of first visible defoliation, the average of percent positive samples increased only slightly to 52%, however, average number of larvae per sample rose to 11. Considerable variation existed

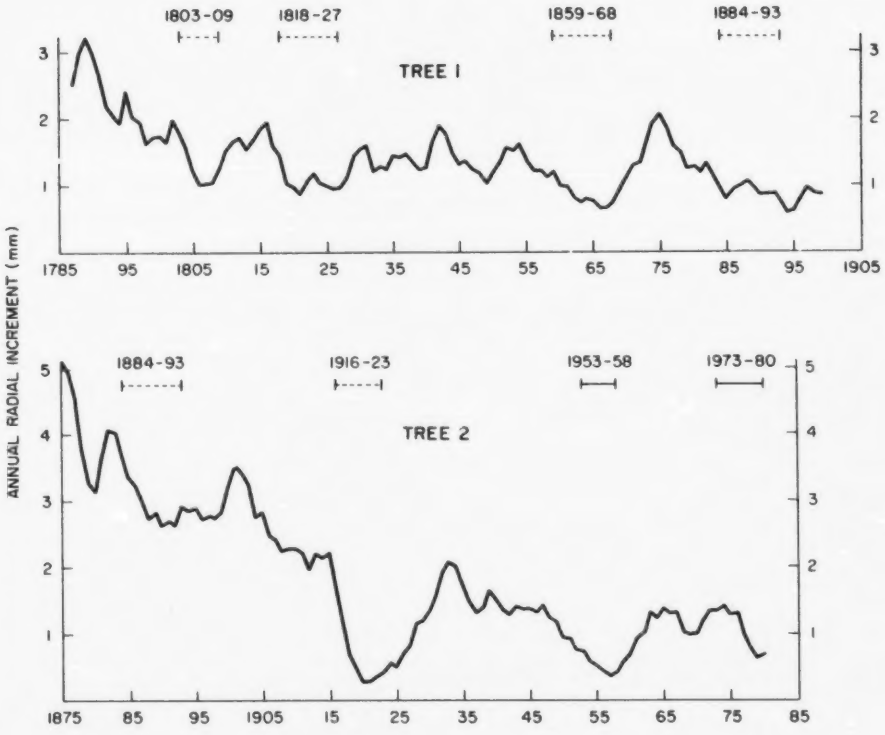

Fig. 6. Annual radial increment of two Douglas-fir trees from Log Creek, near Hope, B.C. (smoothed to 3-year moving averages) showing eight suppressed growth periods during known (⊢—⊣) and suspected (⊢- -⊣) periods of western spruce budworm defoliation, 1787-1980.

both within and between areas (Table 2). In the following years, as defoliation and larval populations peaked, the average percent positive samples increased to 80% (33% in one area) and the average number of larvae per sample rose to 52 (1 per sample in one area). In the first year of significant decline in the area of defoliation positive samples dropped to an average of 57% and the average number of larvae fell to 21 per sample.

Thus, when small areas of defoliation are noted, especially where infestations have occurred in the past, and if the percentage of positive samples increases to 30-50% and the average number of larvae per sample increases to 2 or 3 per sample, widespread defoliation may occur in the following year or two. Such forecasts, however, are subject to change because other regulatory mechanisms such as weather might affect populations.

Acknowledgement

This study was in part a contribution to CANUSA, the Canada — U.S. Spruce Budworms Research Program.

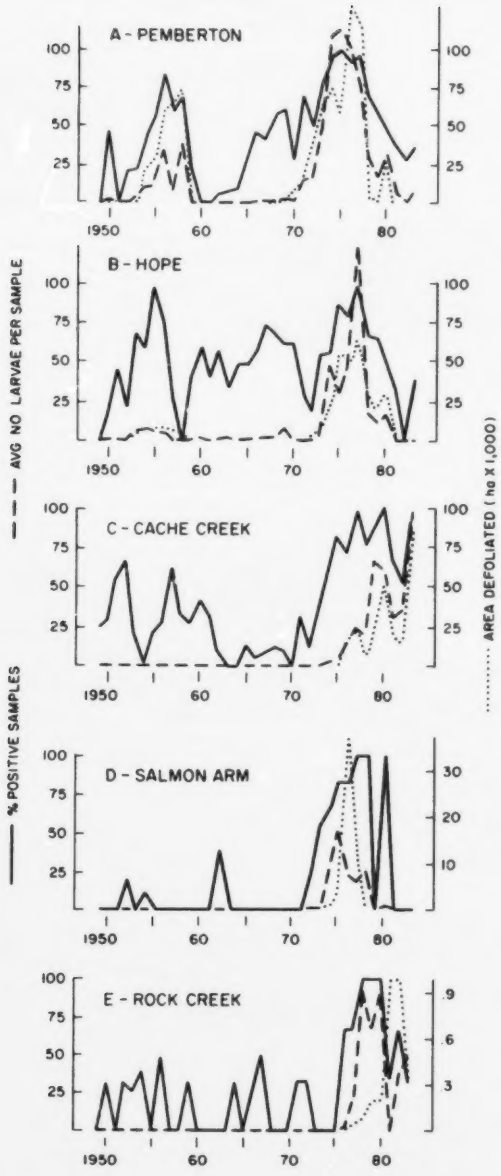

Fig. 7. Average annual western spruce budworm larval populations and area of defoliation of Douglas-fir in British Columbia for selected study areas A-E (Fig. 1) from 1949-1983, showing seven instances of major population increase.

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Table 1. Western spruce budworm infestations in British Columbia, 1909-1983.

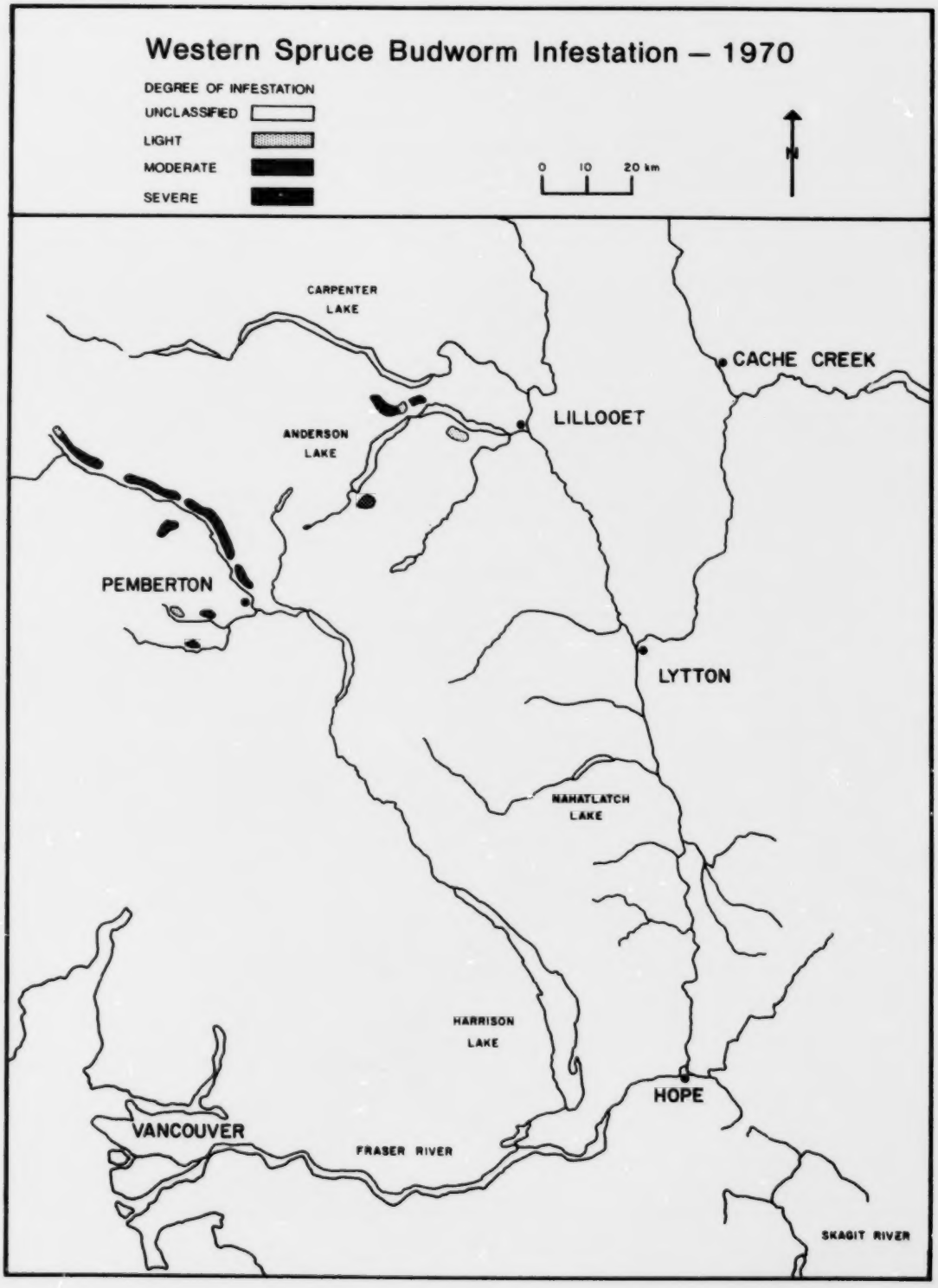
Infestation period	Location	Maximum defoliated area (ha)
1909-1910	S.E. Vancouver Island	not recorded
1916-1919	Lillooet area	not recorded
1923-1930	Bridesville-Rock Creek, S.E. Vancouver Island	1 200 15 000
1943-1946	Pemberton-Lillooet area, Skaist River	46 000
1948-1958	Pemberton-Lillooet area, Fraser Canyon	80 000
1967-1983 continuing	Pemberton, Lillooet, Bridge River, Fraser Canyon, Hope, Skagit-Sumallo rivers, Princeton, Cache Creek, Clinton, Savona, Adams-Shuswap lakes, Rock Creek-Bridesville	226 000

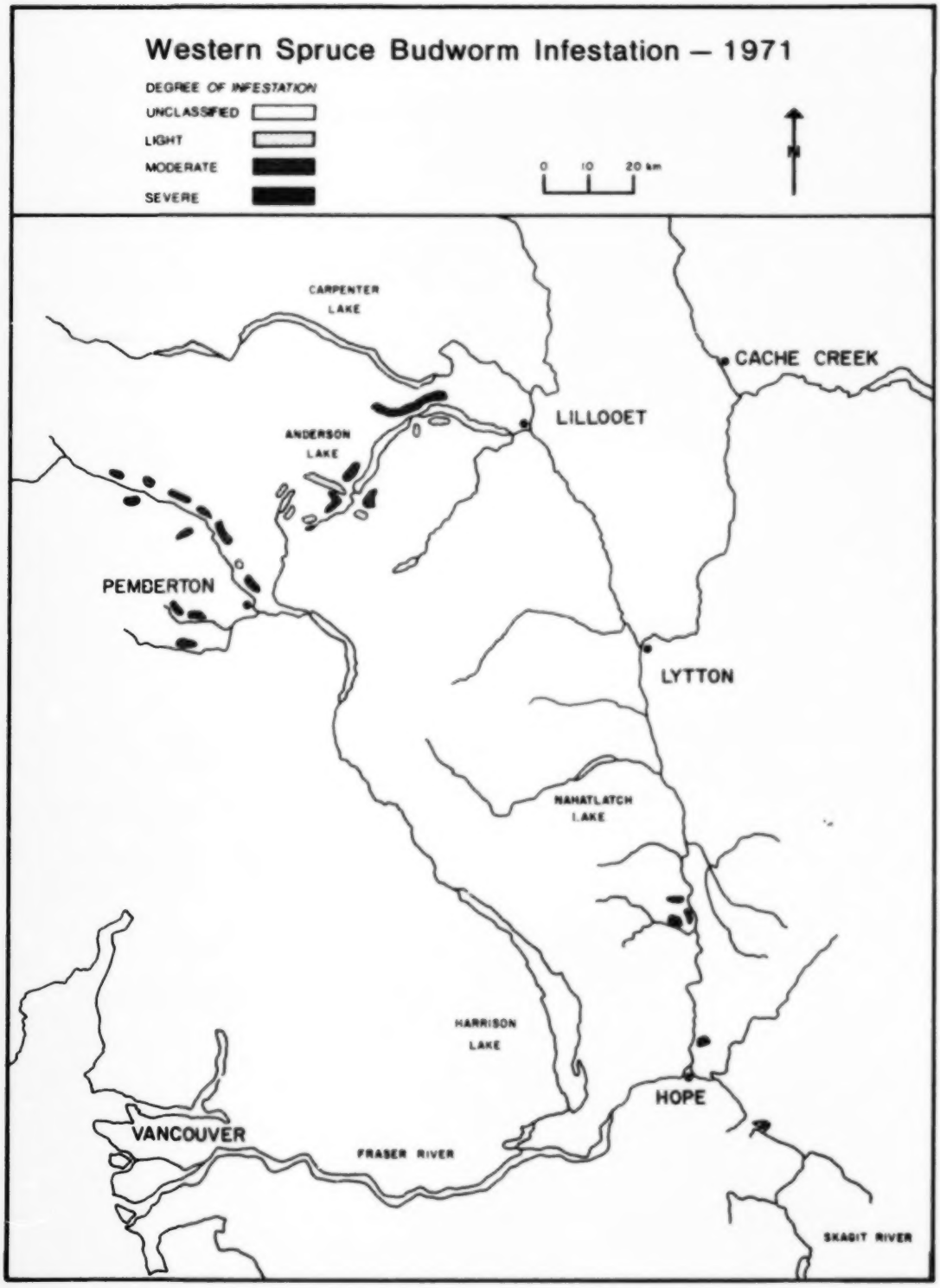
Table 2. Percent positive samples (PPS) and average numbers of larvae per sample (LPS) at selected stages of western spruce budworm infestations in British Columbia, 1949-1983.

Study Area[1]	Two years before visible defoliation		One year before visible defoliation		First year of defoliation		Year of maximum defoliation		Year of significant decline in defoliation	
	PPS	LPS	PPS	LPS	PPS	LPS	PPS	LPS	PPS	LPS
Pemberton	0	0	20	0.5	22	3	71	42	23	1
	25	0.5	47	2	41	1	91	103	67	30
Hope	50	2	20	2	71	7	80	7	43	1
	62	8	62	2	29	1	100	127	67	21
Cache Creek	56	2	83	4	69	13	100	60	64	30
Salmon Arm	50	1	40	6	67	29	83	22	100	18
Rock Creek	0	0	67	2	67	20	33	1	33	48
Avg	35	2	48	3	52	11	80	52	57	21
Range	0-62	0-8	20-83	0.5-6	22-71	1-29	33-100	1-127	23-100	1-48

[1] Study areas are delineated on Figure 1. For the Pemberton and Hope areas, data were available for two infestation periods (Fig. 3).

Appendix 1. Western spruce budworm defoliation maps for southwestern Interior British Columbia, 1970-1983.

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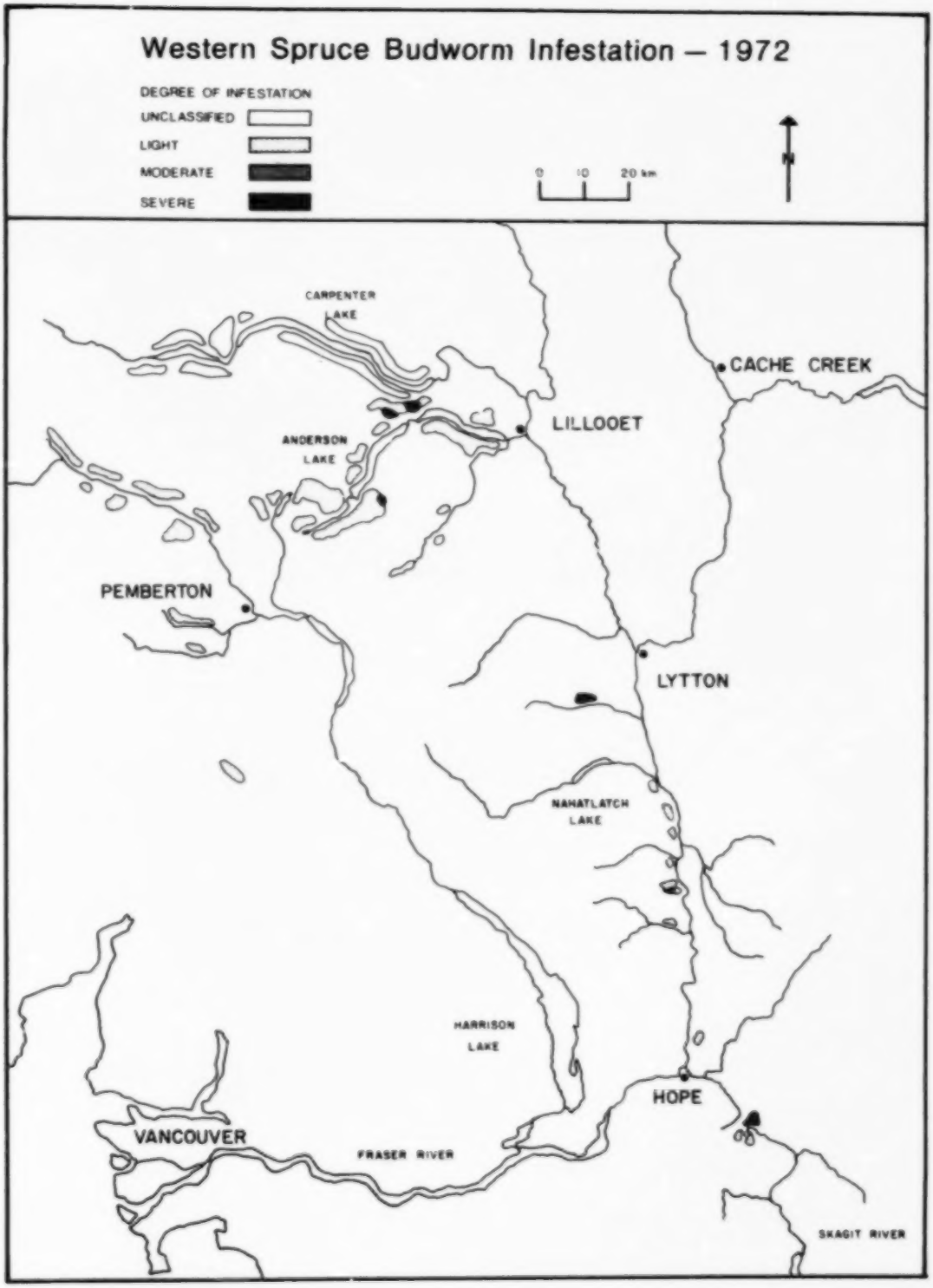
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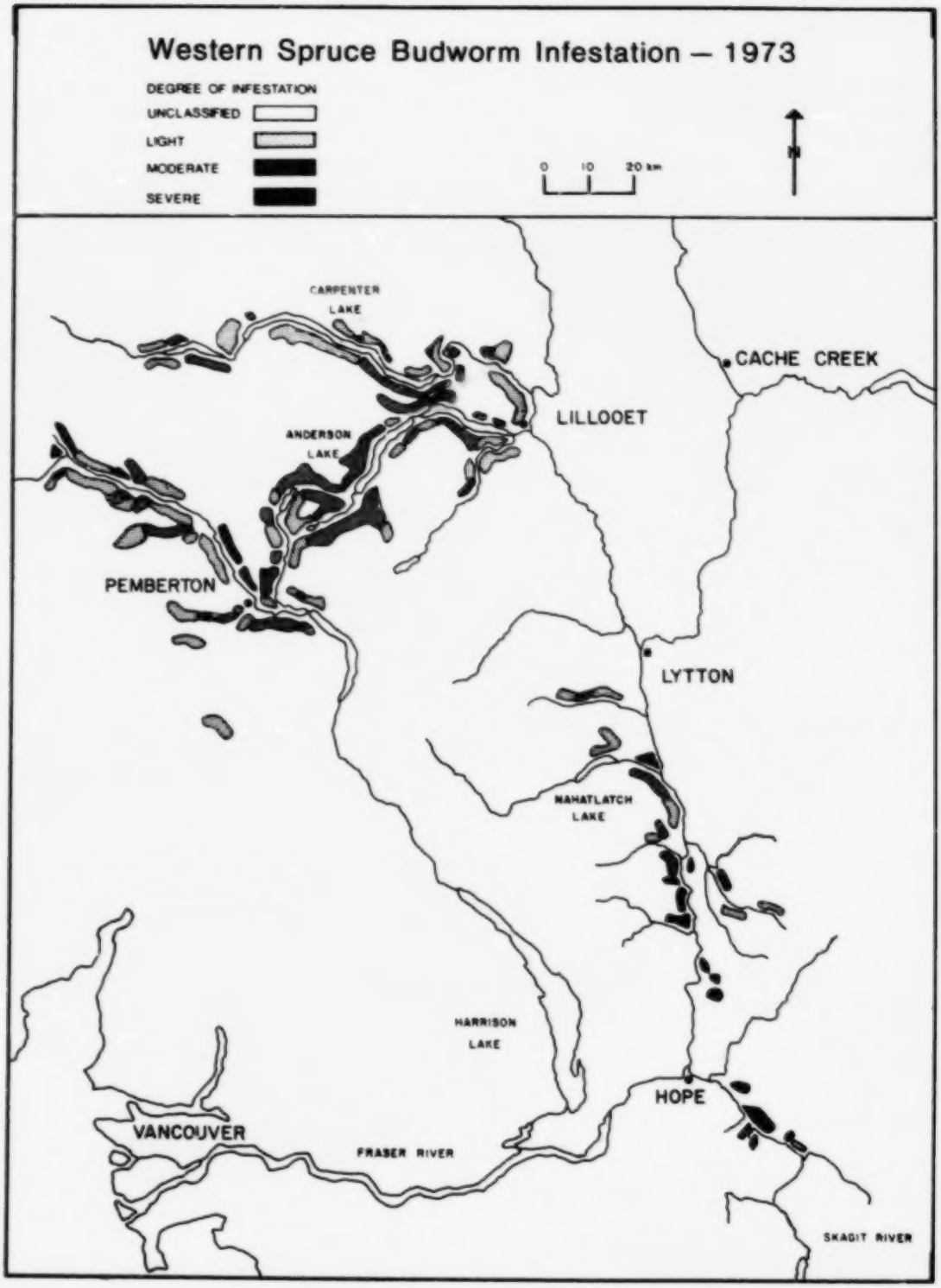
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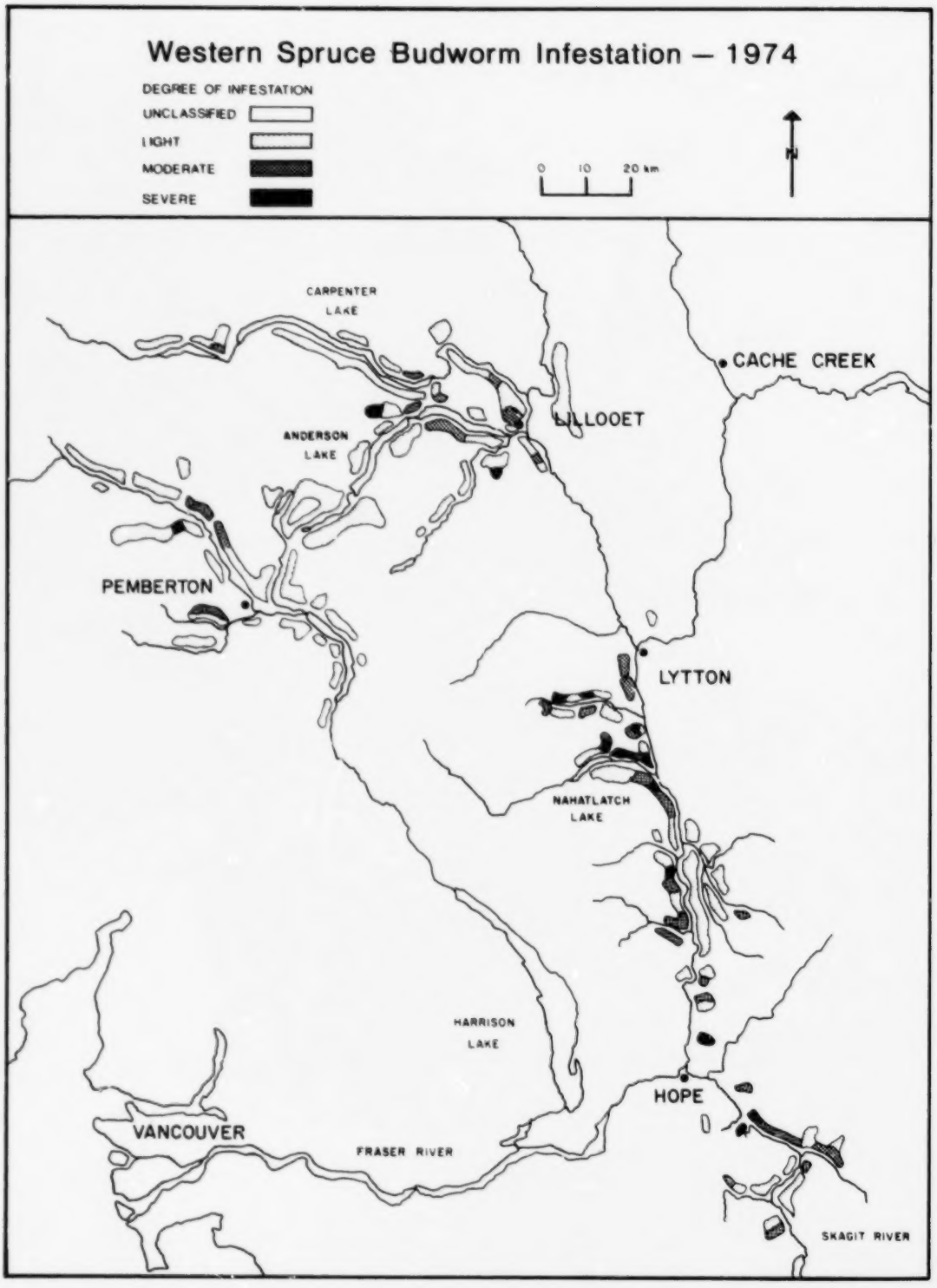
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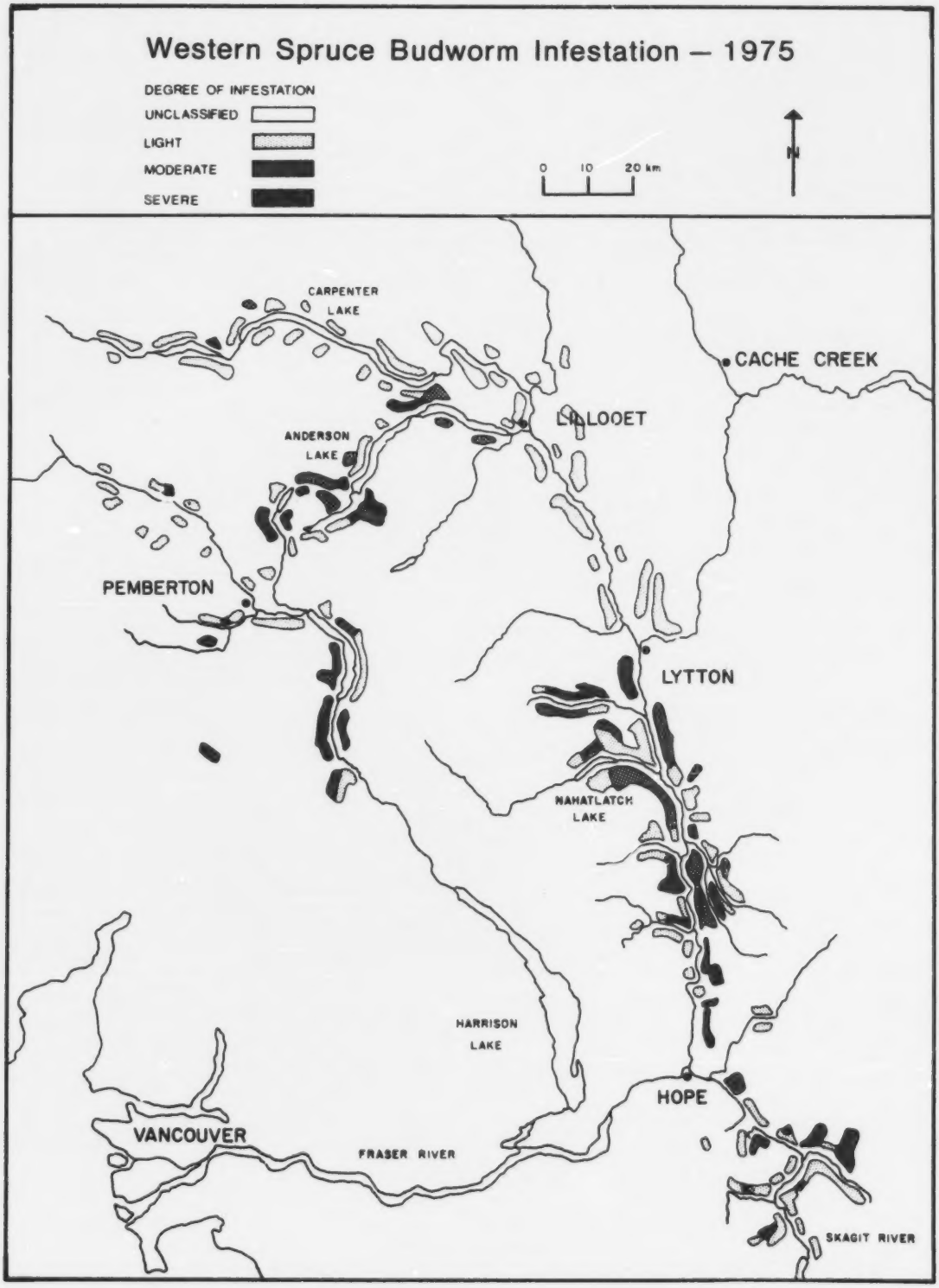
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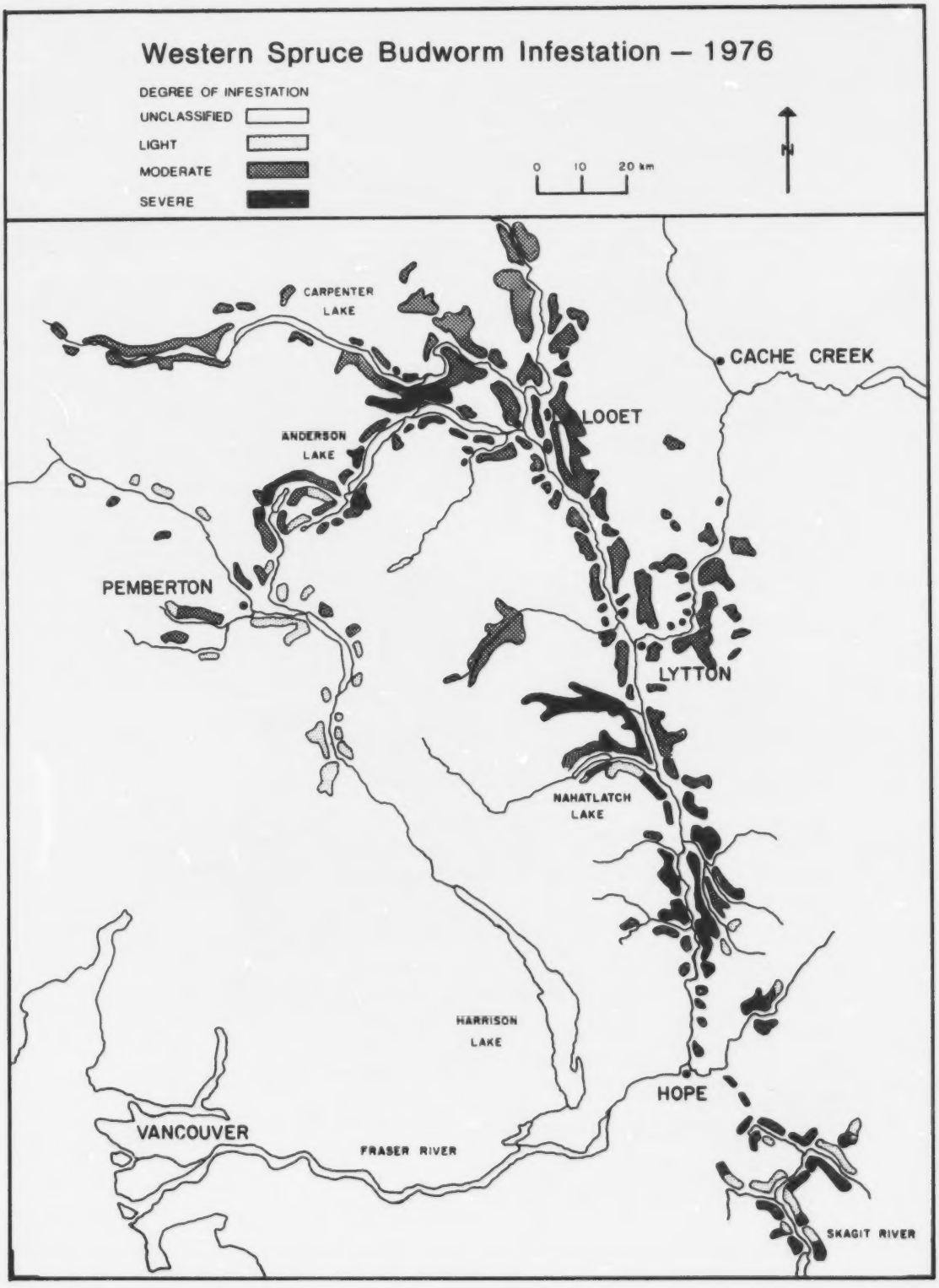
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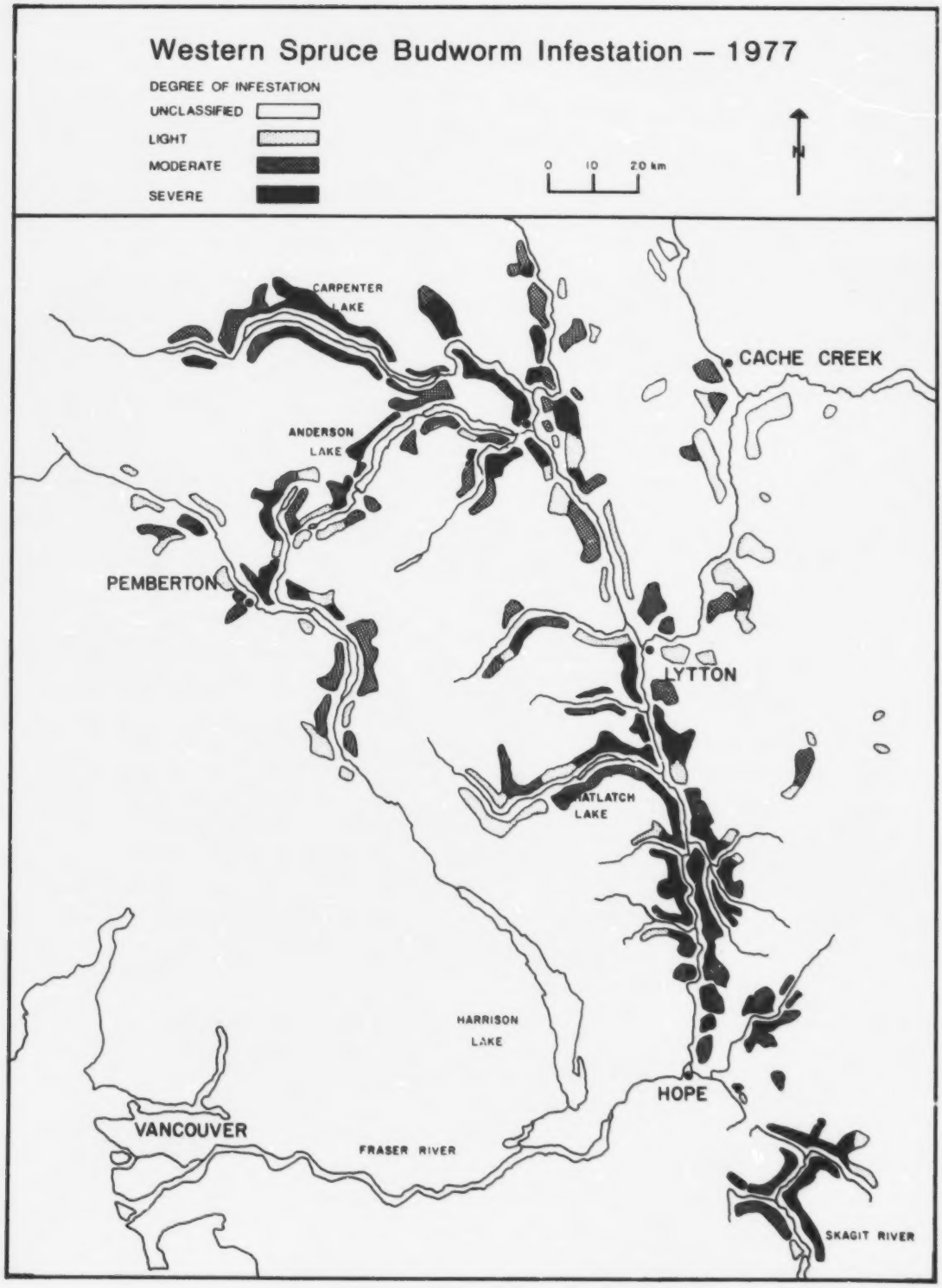
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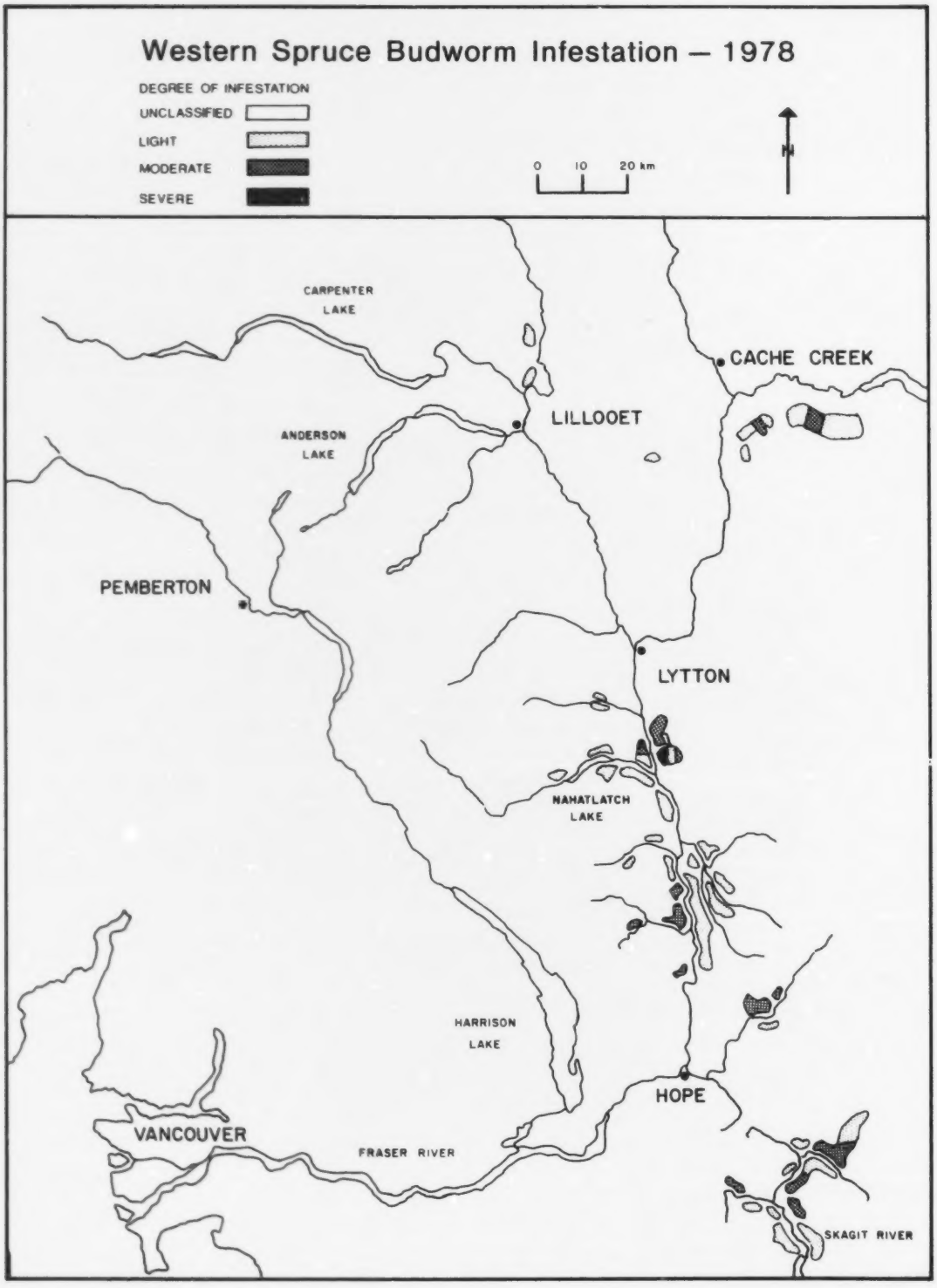
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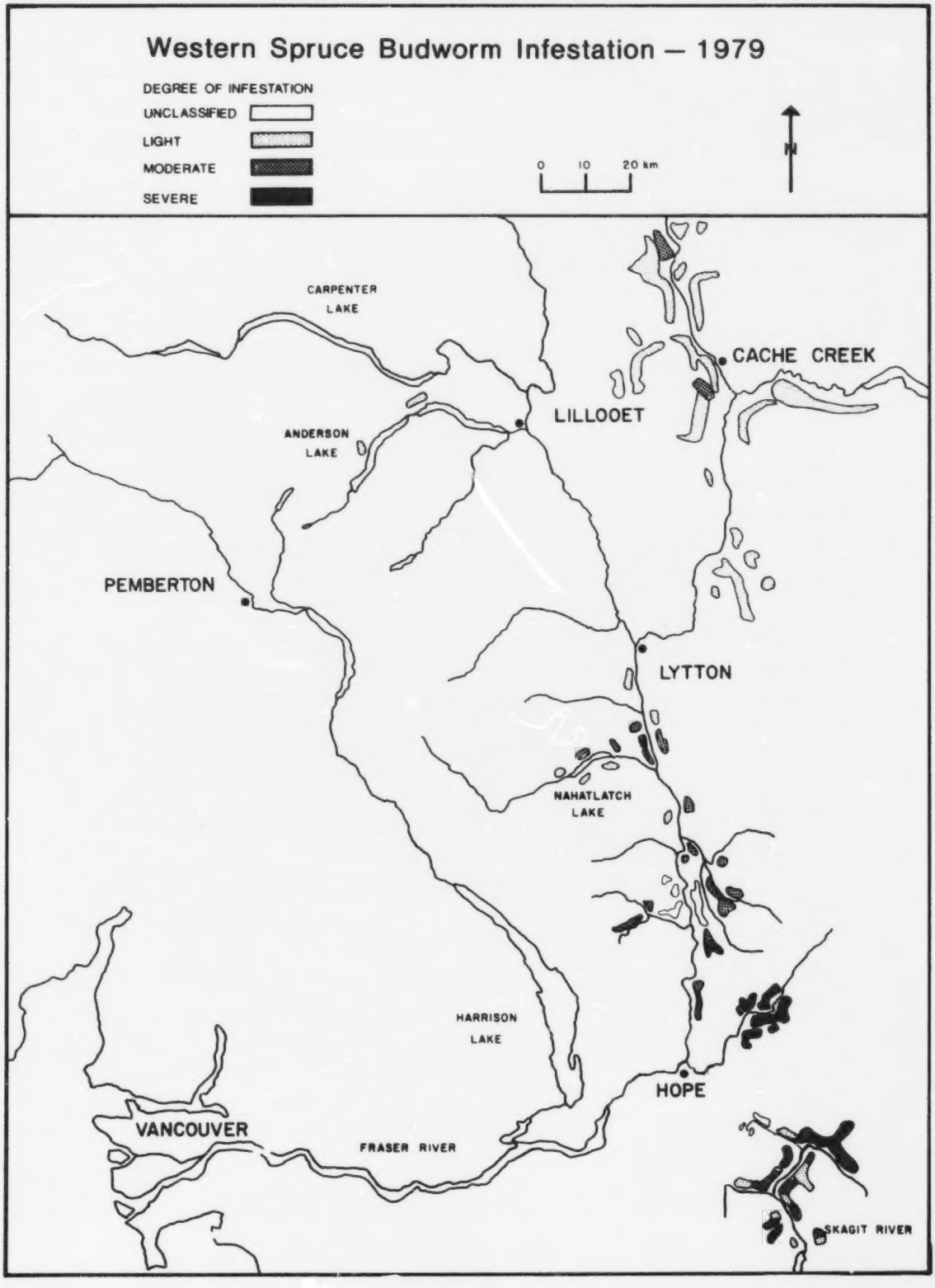
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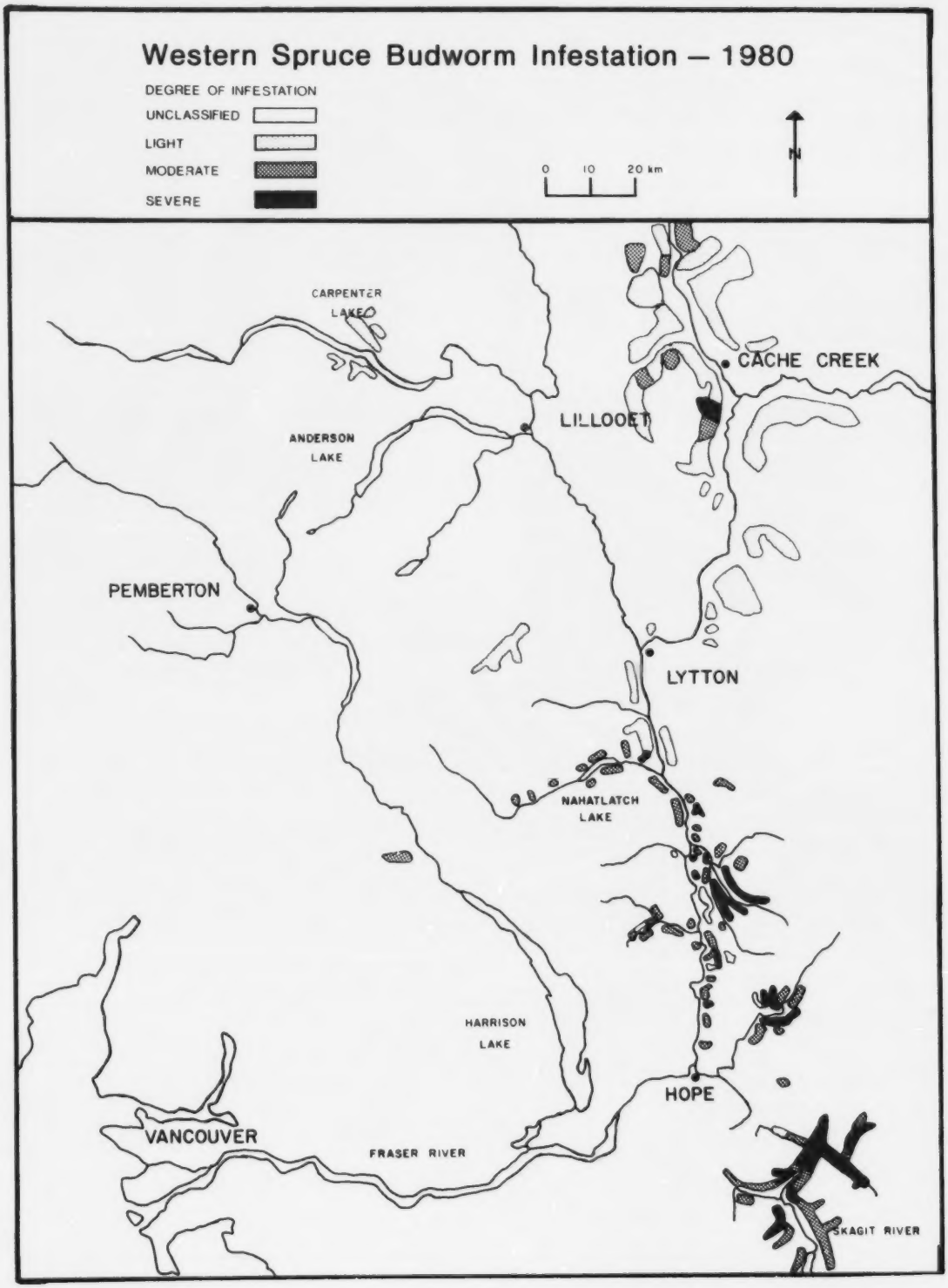
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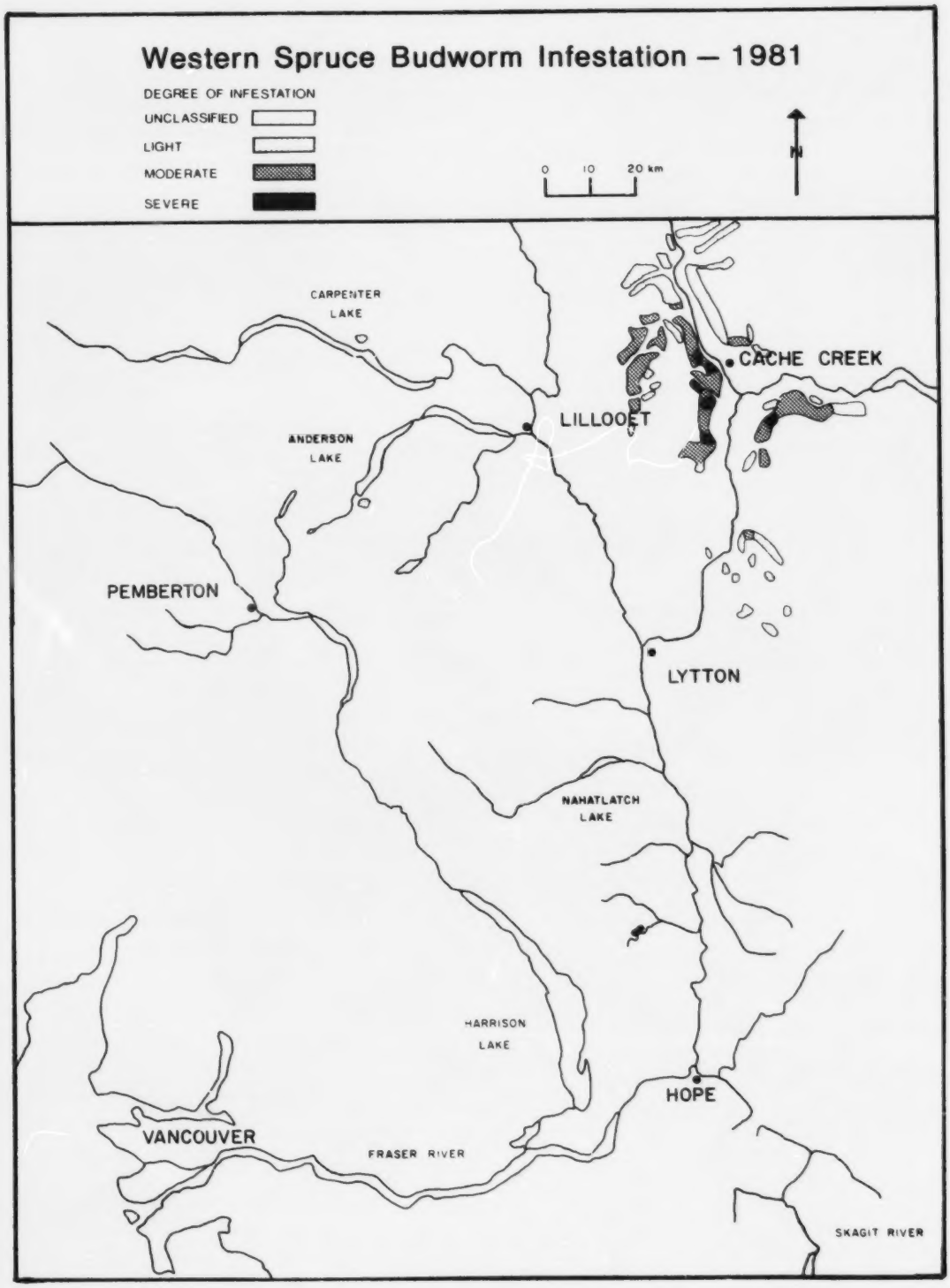
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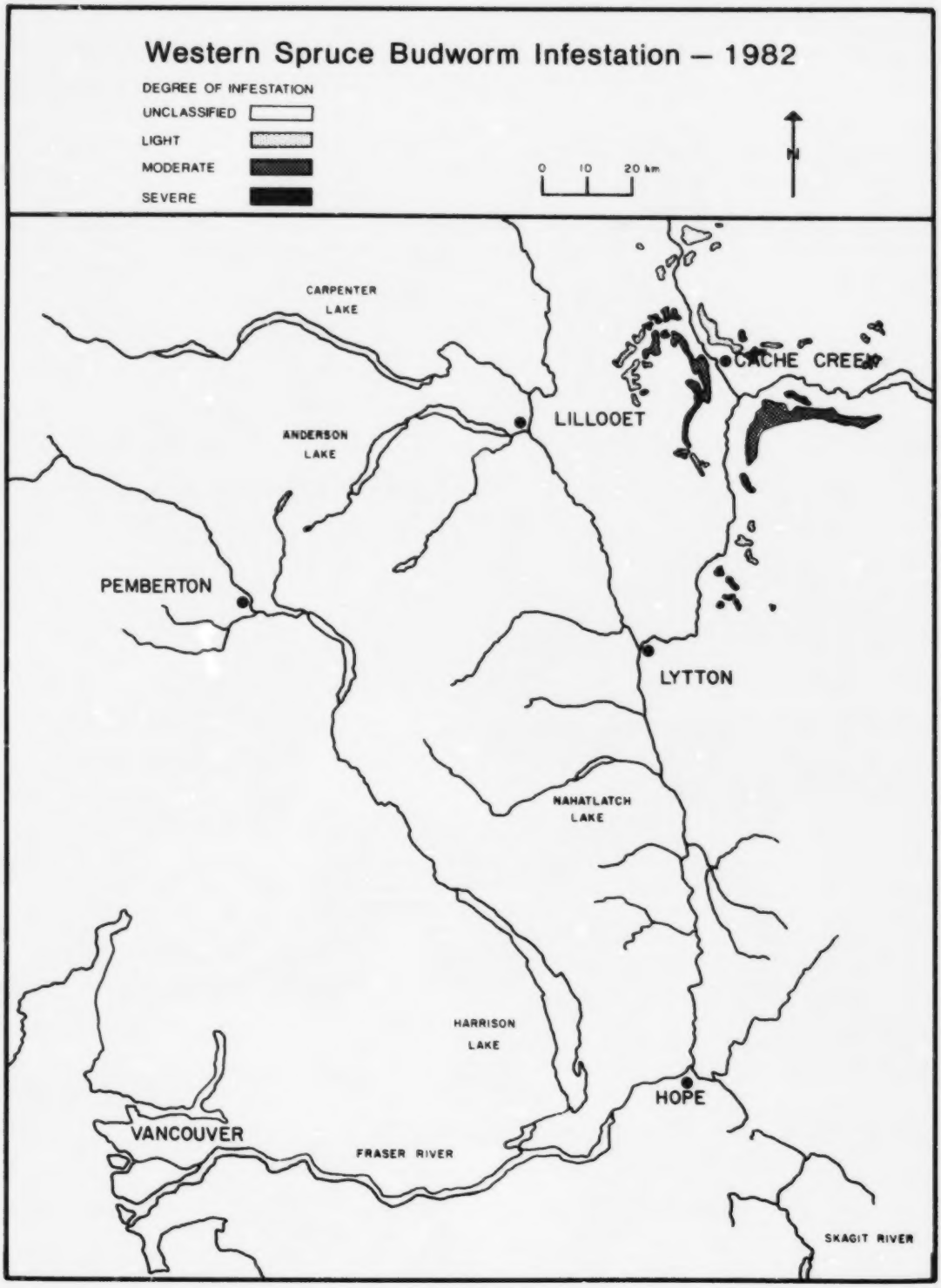
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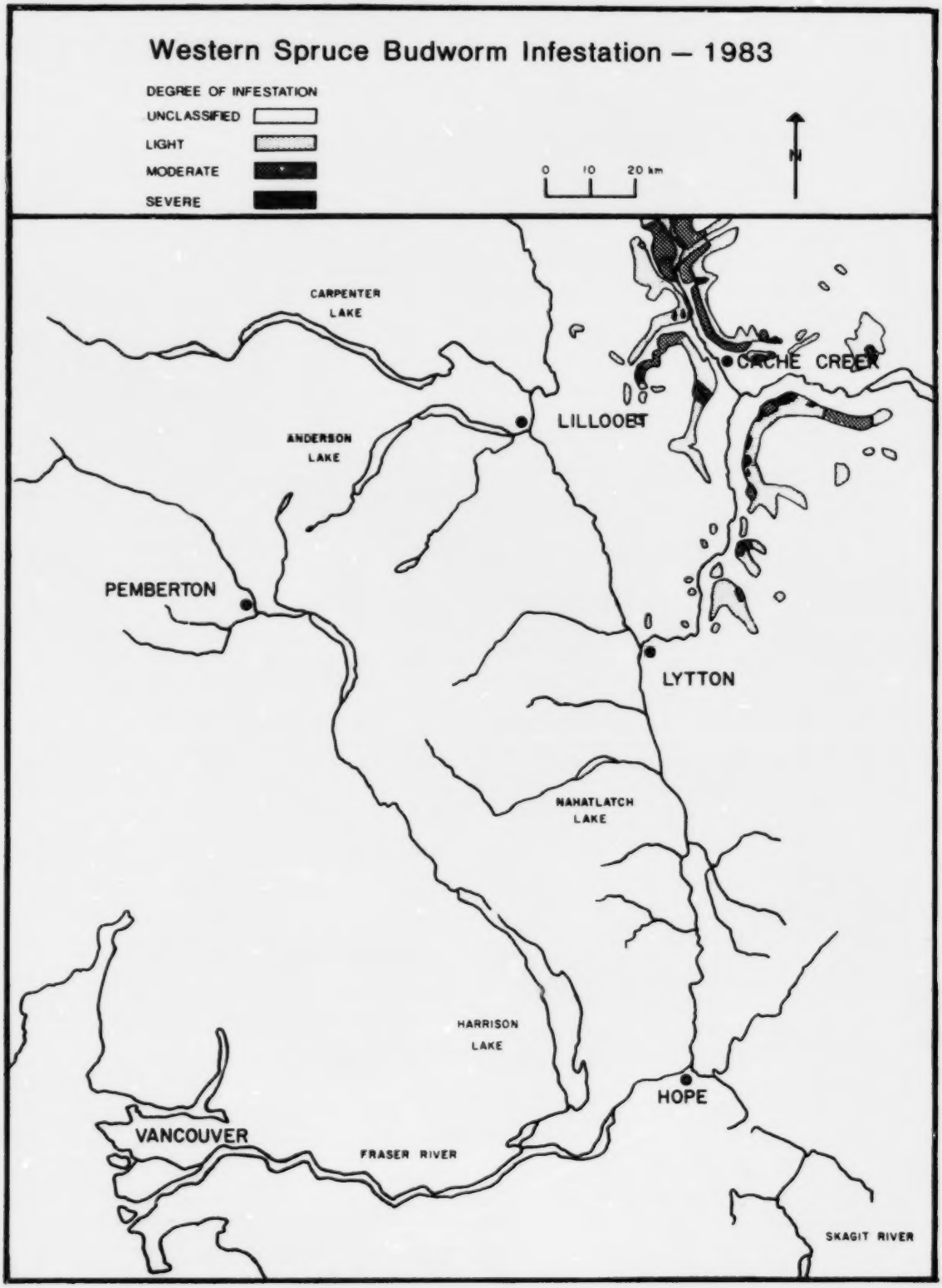
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